

## EFFECT OF PROCESS PARAMETERS ON THE SURFACE INTEGRITY OF MICRO-HOLES OF Ti6Al4V OBTAINED BY MICRO-EDM

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### ABSTRACT

*This paper presents machining of the Ti6Al4V sheet using micro-EDM process. The influence of input parameters such as machining voltage and machining on time on the recast layer, micro-hardness, and change in chemical composition of the machined sample has been investigated. The recast material thickness was estimated from FESEM images corresponding to different pulse-on time duration and voltage with and without assisted vibration of the job. It is observed that by use of ultrasonic vibration to the job, the thickness of the recast layer is comparatively less. The changes in the micro-hardness of the machined workpiece were evaluated using a micro-hardness testing machine and found that the hardness of the fabricated micro-holes improves significantly on the introduction of ultrasonic vibration to the job. The change in element composition of the workpiece surface due to micro-EDM process was observed through EDS analysis. It was observed from the results of the EDS analysis that less amount of the residuals of the carbon and oxygen were present on the surface of the machined sample.*

**KEYWORD:** Micro-EDM, Micro-Cracks, Surface Integrity & Micro-Hardness

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### INTRODUCTION

In the fabrication of micro devices using titanium based alloy (Ti6Al4V) by conventional machining processes like turning, milling and drilling, all of these process having problems of poor machinability [1-3]. However, with the help of advanced machining process like micro electro-spark machining [1-2], micron size feature can be achieved successfully on titanium-based alloy because tool and workpiece are not directly connected together [6].

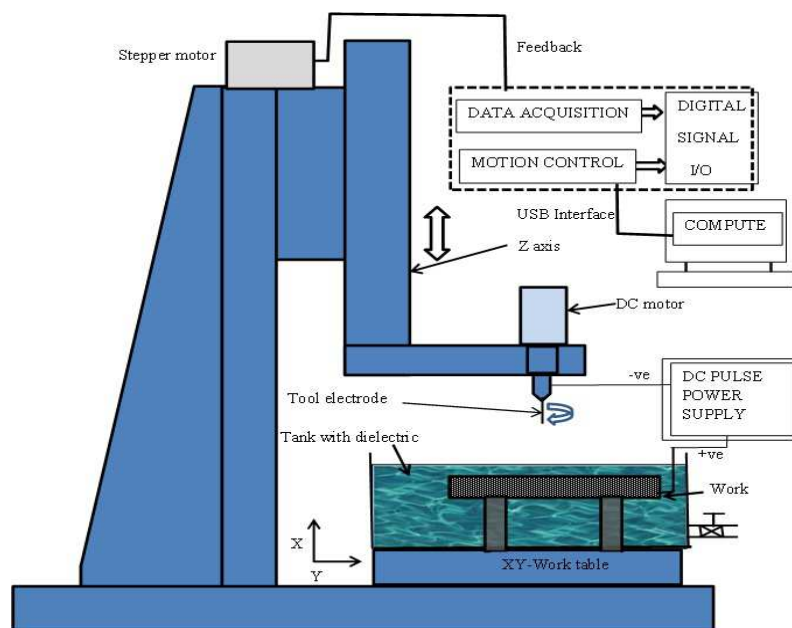
The surface integrity of EDMed surface can be measured in terms of surface roughness, white layer thickness, thermally affected zone, the formation of micro-cracks, residual stress, microhardness, microstructures, and metallurgical alteration under diverse machining settings [7, 8]. [9] Conducted experimentations with distilled water as the dielectric fluid. They reported that the development of micro-cracks has been seen at different pulse time and machining current, the density of micro-cracks rises with the increase of pulse-on time and machining current. Moreover, the machined superficial part was alloyed with both oxides and carbides during the machining operation. [10] Performed experimentations using distilled water as the dielectric fluid for minimizing the environmental pollution because water does not discharge any injurious gases during machining operations. [11] Conducted an experimental investigation on the surface features of Ti-6Al-4V with EDM process using ultrasonic vibration of the workpiece. This investigation reported that with the application of ultrasonic vibration, the size of

the craters increases results in an increase of MRR as compared to the conventional EDM processes.

Titanium and its composites are used in various manufacturing fields, such as aviation, automotive and biomedical due to their high strength-to-weight ratio. Machining of this type of superalloy is very difficult using conventional machining techniques due to their high hardness, toughness as well as low thermal conductivity [12]. Therefore, machining of titanium alloys (Ti-6Al-4V) by un-conventional methods, EDM or micro-EDM, is found to be more appropriate because, in these processes, the machining characteristics depend on the electrical conductivity of the material. In the present investigation, the influence of the machining parameters, such as pulse-on time and voltage, on the surface integrity parameters of titanium alloys (Ti-6Al-4V) has been analyzed for machining of micro-holes [13-14]. Such parameters include recast layer thickness, heat affected zone change in the micro-hardness of the workpiece surface and change in the chemical composition of the machined micro-holes [15-17].

## EXPERIMENTATION DETAILS

In this study, all the designated experiments were conducted on a laboratory scale in-house developed micro-EDM setup which is shown in figure 1. In this research work, the transistor type of pulse generator has been used for conducting experiments. This power source is capable of generating 150V output pulses across a resistive load at a pulse frequency of 100Hz-10 kHz. The developed machine is equipped with a transistor-based pulse power supply whose pulse width and pulse frequency can be programmed through a microcontroller.



**Figure 1: Schematic of the Experimental Setup with a Multipurpose Miniature Machine tool**

## WORKPIECE, TOOL MATERIAL, AND DIELECTRIC MATERIALS

Titanium alloys (Ti6Al4V) has been used as workpiece material with dimensions of 60mm× 50mm× 1mm. Pure tungsten rod of a diameter of 0.5 mm has been used as tool material and 'EDM oil' as the dielectric liquid. The Micro-EDM process parameters and experimental layout have been shown in Table 1.

**Table 1: Parameter Settings for Fabrication of Micro-Holes**

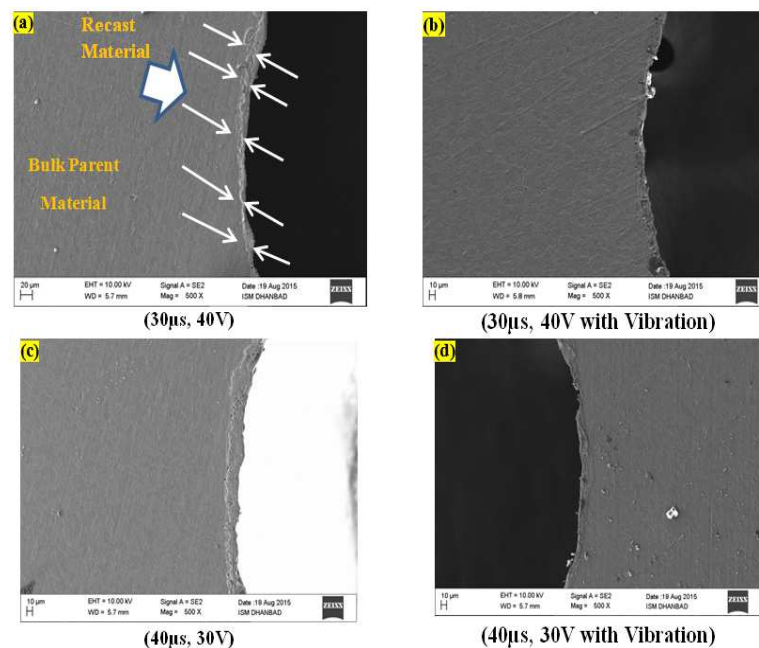
Work piece material	Ti6Al4V Sheet
Tool Material	W: $\phi$ 500 $\mu$ m
Dielectric Liquid	EDM oil
Gap Voltage (V)	30, 40, 50, 60
Pulse-on time ( $\mu$ s)	30, 40, 50, 60
Pulse Frequency	10 KHz

## RESULTS AND DISCUSSIONS

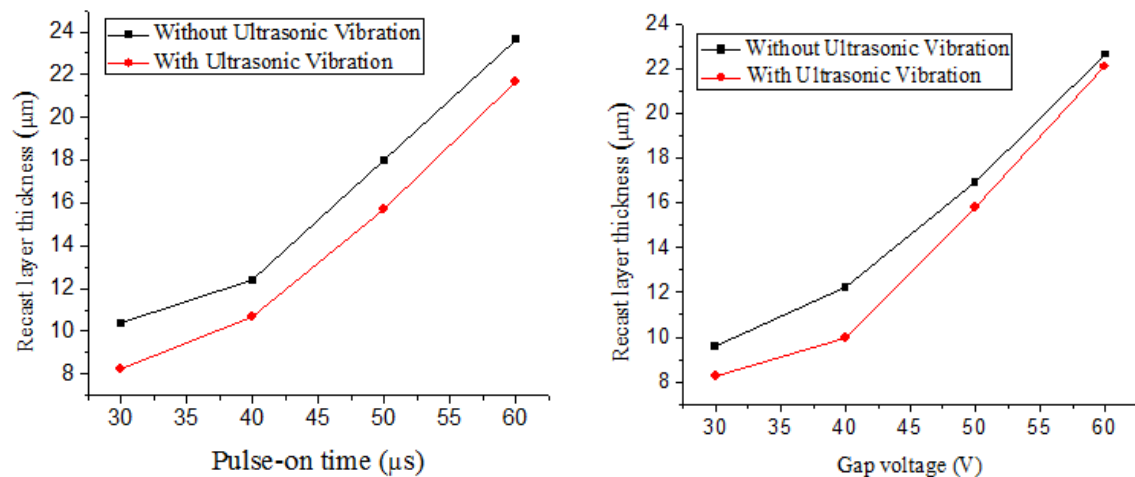
### Variation of Recast Layer Thickness

In this experiments the thickness of the recast layer for every fabricated micro-holes was evaluated from the FESEM images using image processing software. An average recast layer thickness of the micro-holes has been estimated by calculating the average recast layer area. The recast layer thickness was different for every machined hole. Figure 2 shows the FESEM images, captured at the edge of the machined micro-holes at different parameter setting. Figures 2 (b) and (d) have a smaller white layer thickness in contrast with figures 2 (a) and (c), due to use of ultrasonic vibration to the workpiece.

Figure 3 (a) indicates that on increasing pulse-on time duration, the thickness of the white layer increases in both with and without ultrasonic vibration of the workpiece. But the white layer thickness is lower in case of assisted ultrasonic vibration of the workpiece. With assisted vibration, less amount of molten material re-solidified on the workpiece surface. Figure 3 (b) also reveals that in the increase of the gap voltage, the thickness of the recast layer increases in both with and without the aid of ultrasonic vibration to the workpiece. The recast layer thickness of the EDMed surface is increasing in both figures 3 (a) and (b) due to the increase of values of pulse-on time duration and gap voltage. On increasing pulse-on time duration and voltage, the melting of material becomes more resulting in greater penetration in the parent metals and therefore the thickness of the recast layer increases.



**Figure 2: FESEM Image at Different Machining Parameters (a) and (b) at 30 $\mu$ s Pulse-On Time, 40V Gap Voltage; (c) and (d) at Gap Voltage of 30V, 40 $\mu$ s Pulse-On Time**



**Figure 3: Variation in Recast Layer With (a) Pulse-On Duration; (b) Gap Voltage**

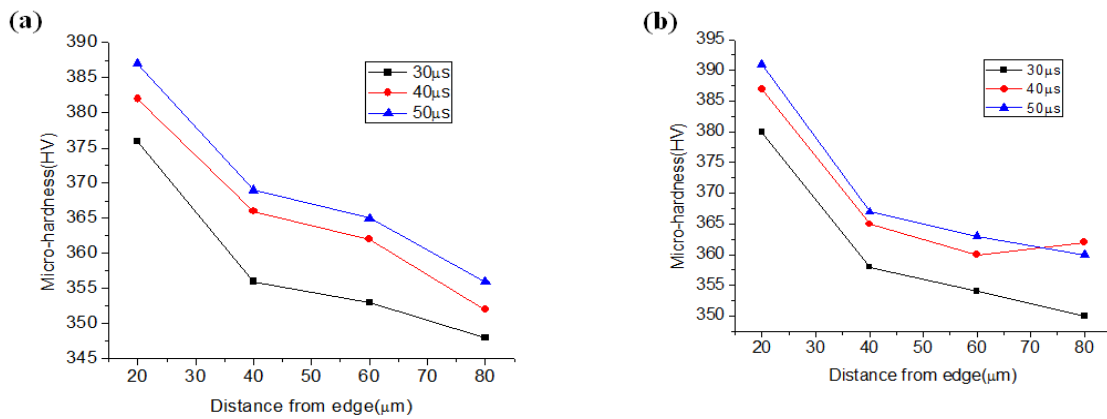
### Effect of Process Parameters on Micro-Hardness

The microhardness of the recast material, heat affected region, and the parent material were tested by the Vickers hardness tester. The hardness values were taken from the edge of the micro-holes to the region of the parent material at a gap of 20 μm between the holes. It has found that with the increase in the distance from the edge of the micro-holes, the values of micro-hardness decreases because of the comparatively a lesser amount of heating and cooling. The hardness of the recast layer varied between 346HV to 392HV. Higher values of hardness in the recast layer are due to rapid heating and cooling of the machined micro-holes. The variation of micro-hardness from the edge of the fabricated holes with and without ultrasonic vibration is shown in figure 4.

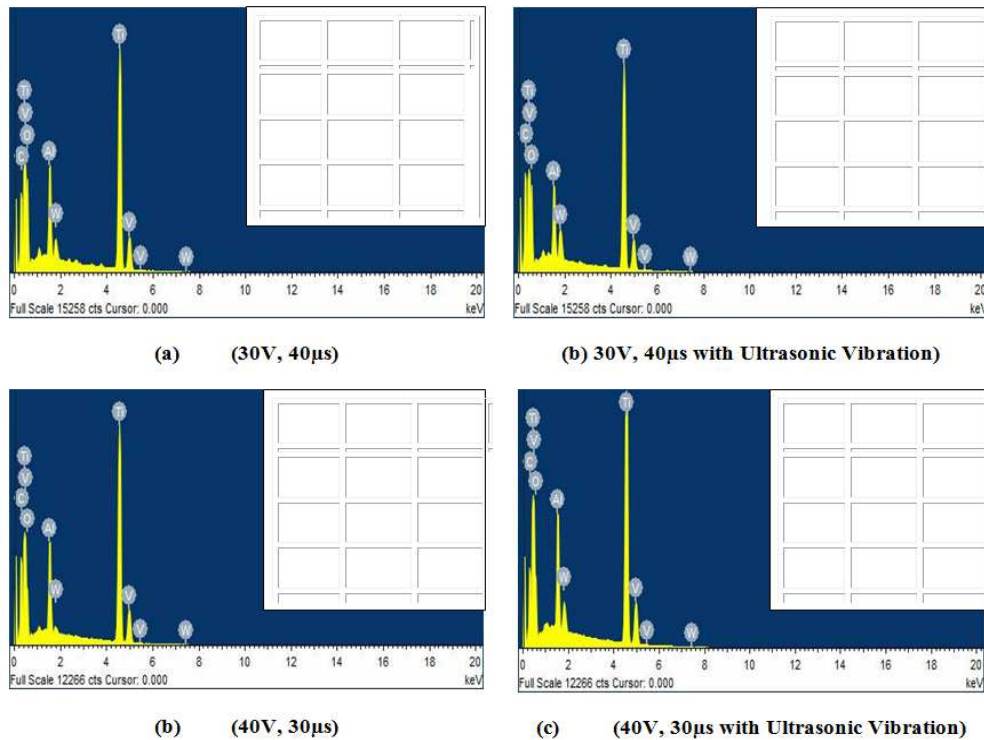
### Energy Dispersive Spectroscopy (EDS) Analysis

In this study, the change in the chemical composition at the edge of the fabricated micro-holes has been characterized using EDS analysis. It has been found that the chemical composition at the edge of the micro-holes was different for every machined micro-holes.

Figures 5 (a) to (d) indicated the EDS plot at different parameter settings. It has been observed that the residuals of carbon, oxygen and tungsten were present in the machined samples and the percentage compositions of carbons, oxygen, and tungsten were different for every sample. In figures 5 (a) and (b), the percentage composition of carbon, oxygen, and tungsten were different which may be due to fact that both samples were machined at different parameter settings. In figures 5 (c) and (d), the percentage composition of carbon, oxygen, and tungsten reduces significantly on the introduction of vibration to the workpiece.



**Figure 4: Variation in Micro-Hardness from Edge of the Hole**  
**(a) Optical Micrograph Indicating the Penetration of the Tip of Diamond Indenter;**  
**(b) Influence of Pulse-On Time**



**Figure 5: EDS Plot and their Chemical Composition at Different Parameters**  
**(a) and (b) Without Vibration and (c) and (d) with Vibration**

## CONCLUSIONS

With the view of advanced micromachining process, the surface integrity of machined micro-holes on Ti6Al4V has been carried out. This investigation primarily analyses of recast layer thickness, micro-hardness and metallurgical transformation on the EDMed surface with different machining setting. The main conclusions from the experimental studies are:

- The recast layer thickness was measured for the entire machined holes. The average thicknesses of the recast layer obtained were in the range of 7-24 μm. The thicknesses recast layer obtained were lower for ultrasonic vibration

of the workpiece.

- The micro-hardness of the machined workpiece surface was measured for all the three layers, i.e. recast layer, HAZ and in the zone of parent materials. The obtained micro-hardness was highest in the zone of the recast layer and lowest in the zone of parent or bulk materials. The obtained micro-hardness was in the range of 395-348 HV.
- The residuals of the carbon, oxygen, and tungsten have been found at the periphery of the fabricated hole in the EDS analysis.

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